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On Orbit Performance of the Defense Meteorological Satellite Program (DMSP) 5D3 Spacecraft Power System

December 30, 2011

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14. ABSTRACT

This report provides an analysis of the orbital performanee of the three DMSP 5D3 spaeecraft presently on orbit. The mission of the DMSP spacecraft is to collect and disseminate global high-resolution visible and thermal cloud cover imagery for DoD forces and the intelligence community. The present two-satellite constellation (early morning and mid morning) has an inclination of 98.7° with a 458 nmi sun synchronous polar orbit. The orbit period is 101 min with eclipses lasting up to 35 min. The satellites complete 14.2 revolutions around the Earth each day.

The report presents data from the satellite telemetry that will allow determination of the spacecraft power demand for the range of sun angles and spaeecraft configurations for the three operational 5D3 spaeeraft. This is used in determining spacecraft energy balance margins under various operating conditions.

15. SUBJECT TERMS

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Energy Technology Department
April 18 – 21, 2011

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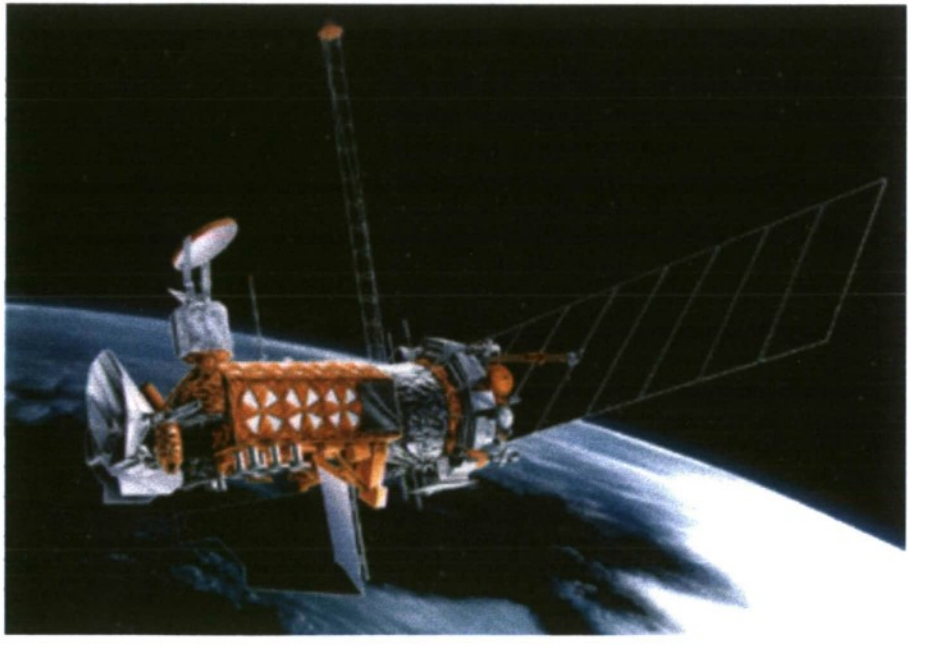
History of DMSP 5D3 Spacecraft

- The build of five 5D-3 spacecraft was completed in 1997
- The first 5D-3 satellite designated F-16 was launched on October 18, 2003 after six years of storage
- The second 5D-3 DMSP designated F-17 was launched on November 4, 2006
- The third 5D-3 DMSP designated F-18 was launched on October 18, 2009
- The final DMSP satellite will not be launched until 2014 or later!

DMSG Mission Description

- Collect and disseminate global high-resolution visible and thermal cloud cover imagery to DoD forces and the intelligence community
- Two satellite constellation (early morning and mid morning)
- 98.7 deg inclination
- 458 nm sun sync polar orbit
- 101 min period with up to 35 minutes eclipse per orbit
- 14.2 revs/day



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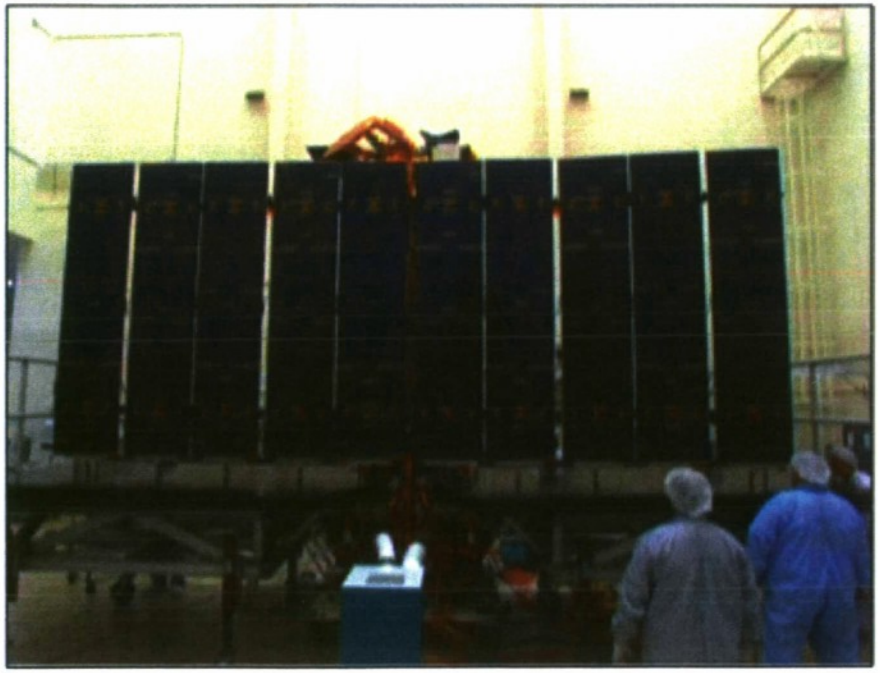
DMSP 5D-3 Spacecraft Power System

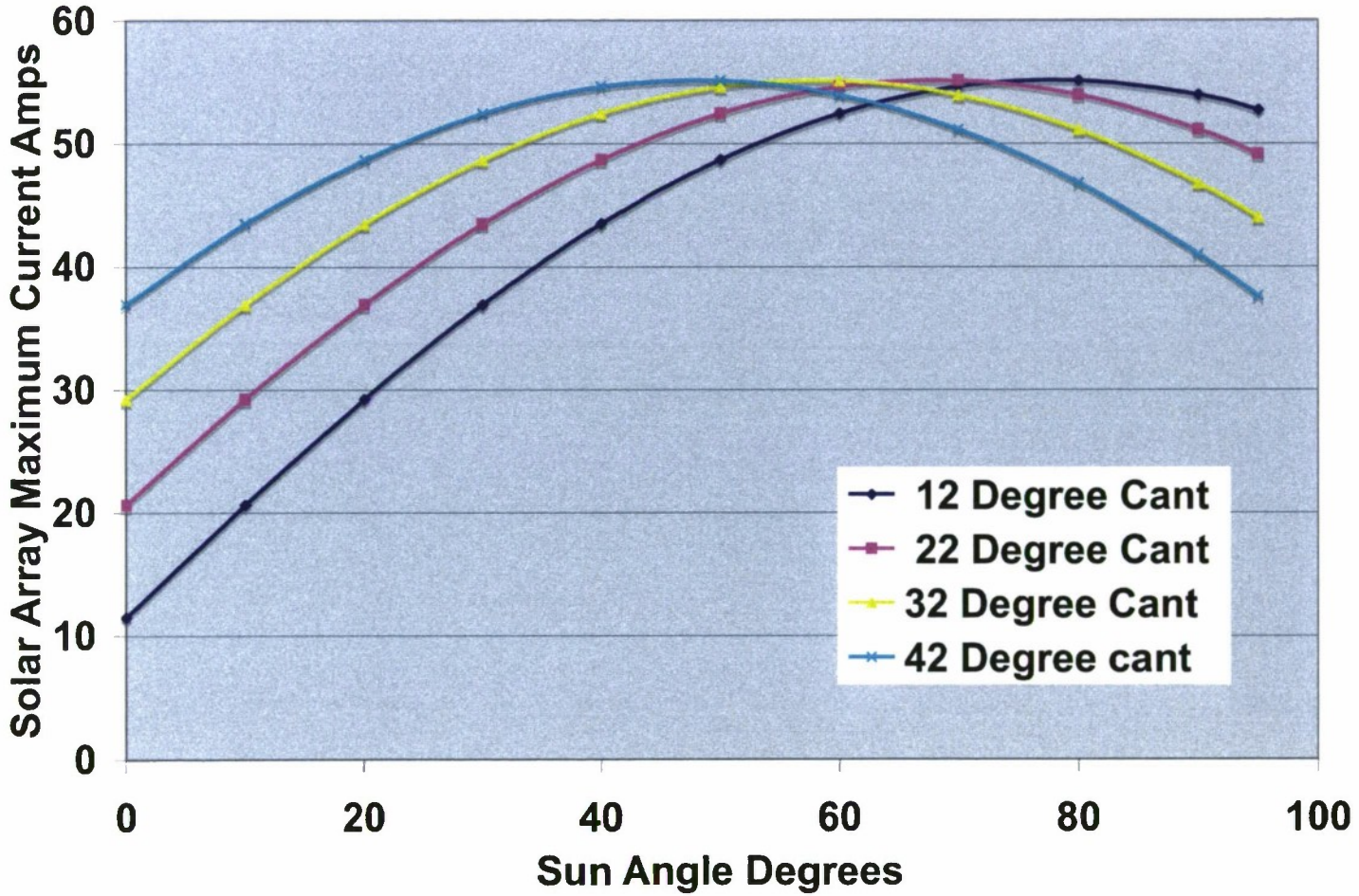
- Direct energy transfer configuration
  - *Solar array partial shunt regulation*
  - *Battery boost regulation*
- Solar array
  - *10 co-planar panels each with 21 series strings with 89 or 90 silicon solar cells*
  - *Single axis tracking by rotating solar array around Z-axis once per orbit*
  - *Capability to command solar array to point off of sun (SADLAG)*
- Battery
  - *Three 17 – cell SAFT 40 AH NiCd batteries*

Solar Array Design Features

- The solar array boom can be canted with respect to the +Z axis of the spacecraft from 12° to 42° in 5° increments
- The cant is set prior to launch and cannot be changed on orbit
- The DMSP Solar Array is a single axis tracking system
- The single axis of tracking is accomplished by rotating the solar array around the boom once per orbit



Impact of Single Axis Tracking and Preset Cant Angle

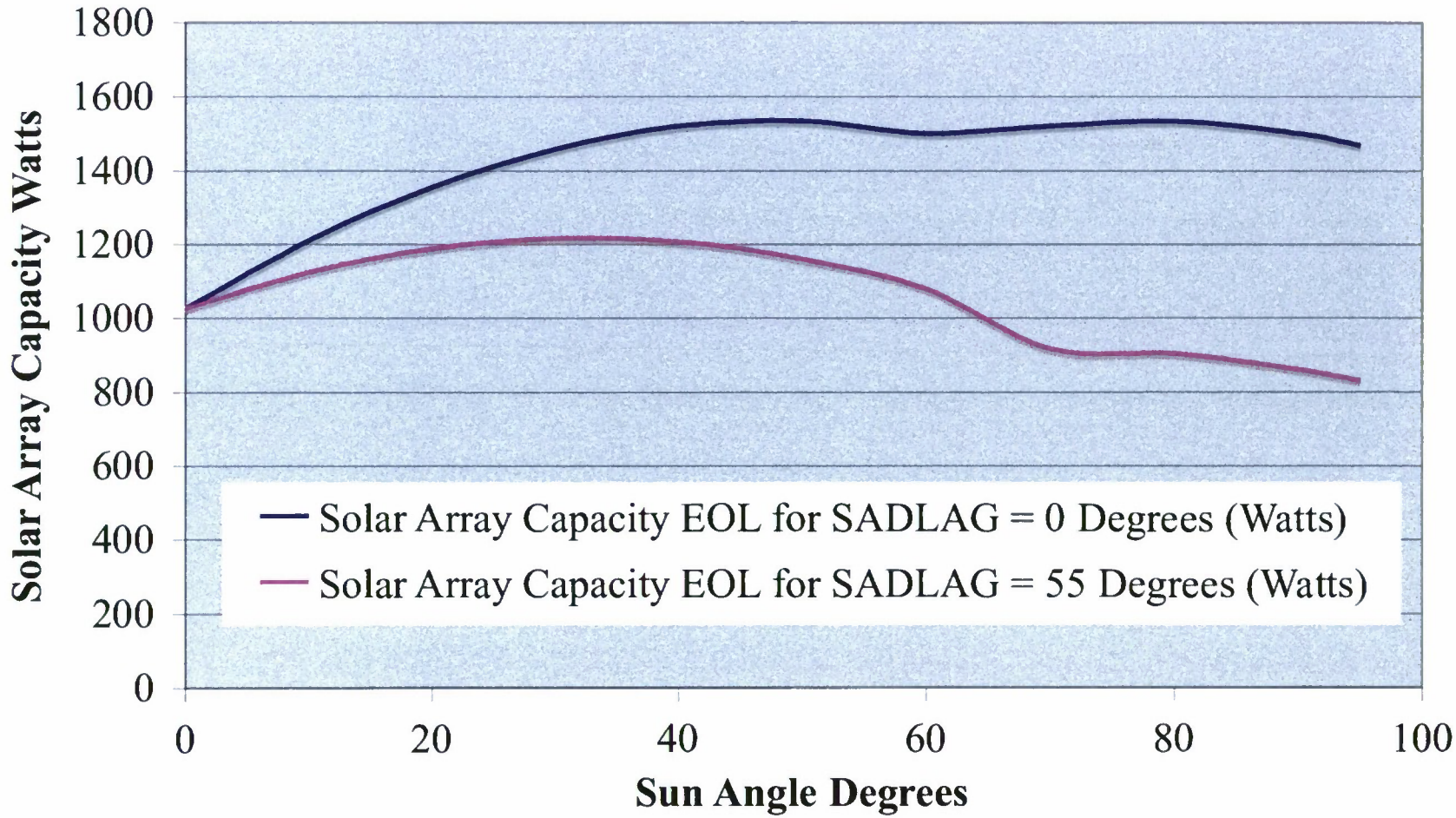


Solar array output as function of sun angle and preset cant angle after five years on orbit in the month of June

Spacecraft Load Varies with Sun Angle, Solar Array SADLAG, and Spacecraft

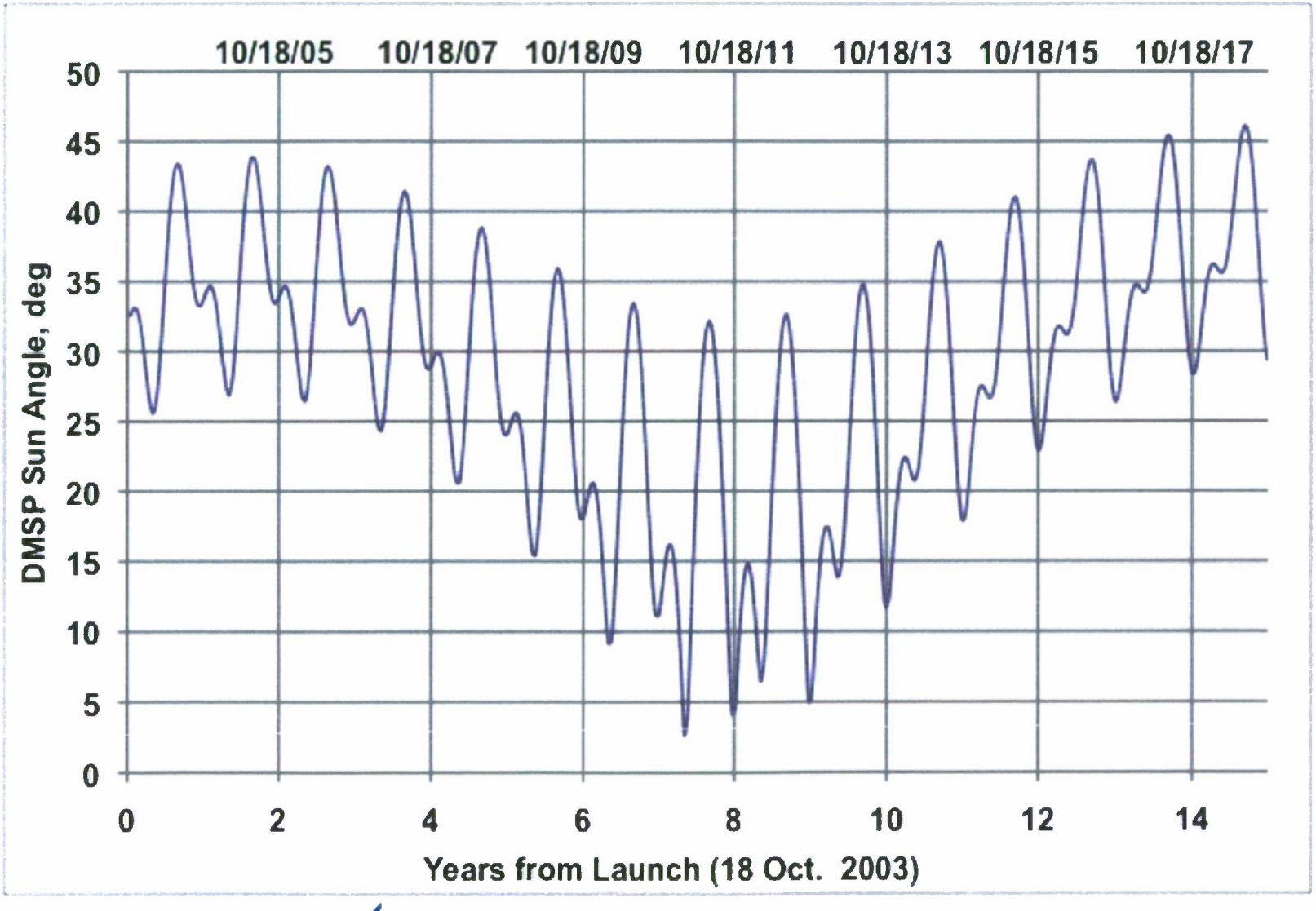
- F-16 and F-18 Sun angle predicted to vary between 0° and 45° over lifetime
- F-17 sun angle predicted to vary between 0° and 30° over lifetime
- F-16 and 17 implemented SADLAG of 55° for sun angles greater than 15° to cool battery 3
- F-17 and 18 have addition of miniature inertial measurement unit (MIMU)
- F-18 had the radiator on battery 3 enlarged eliminating the need to SADLAG the solar array to shade battery 3

Solar Array Capacity



- Solar array capacity as function of SADLAG and sun angle with optimal cant angle after 5 years on orbit

DMSP F-16 Spacecraft Sun Angle Prediction



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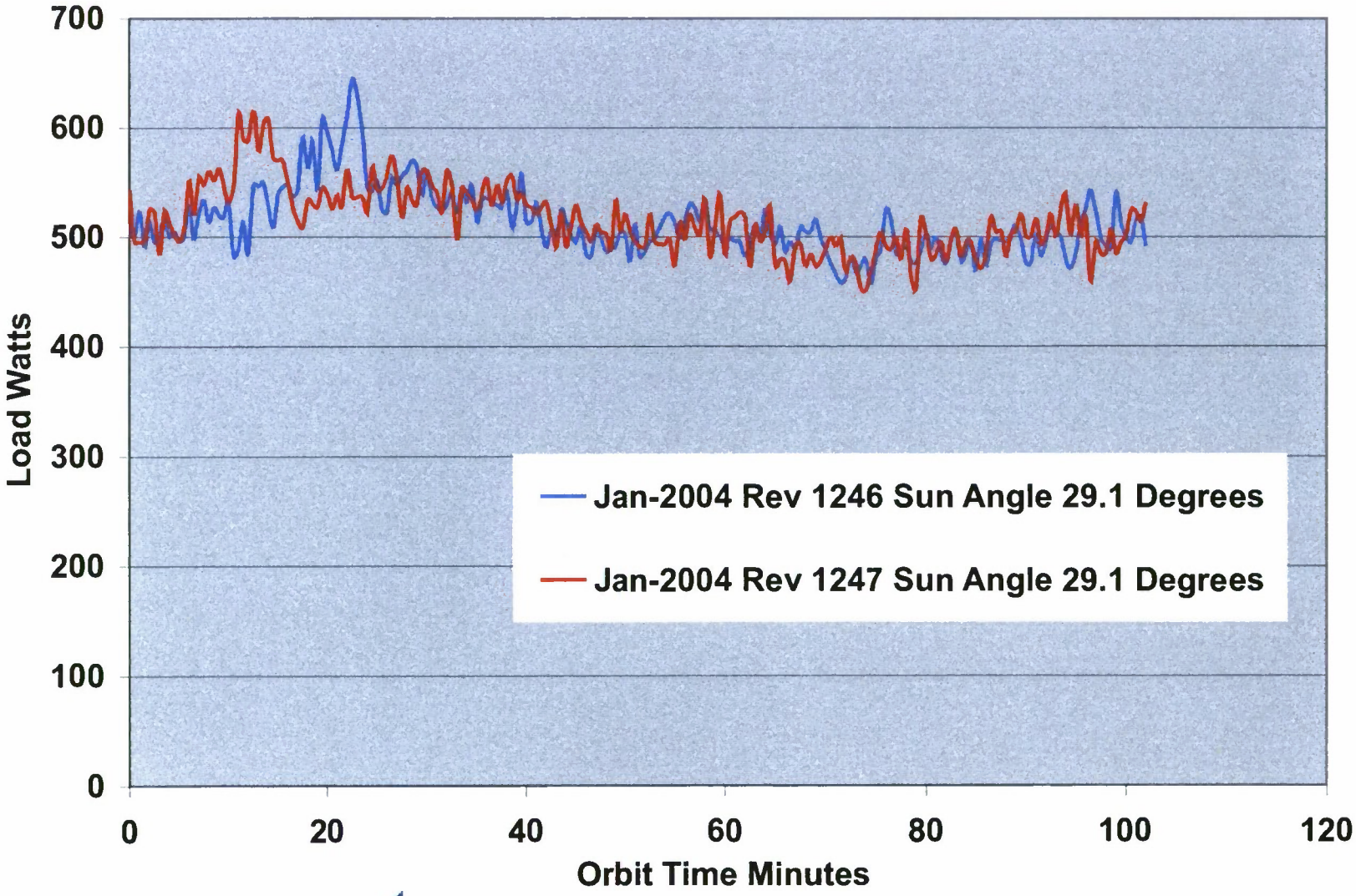
F-16 Load Data for Sun Angle 30° with SADLAG of 0°



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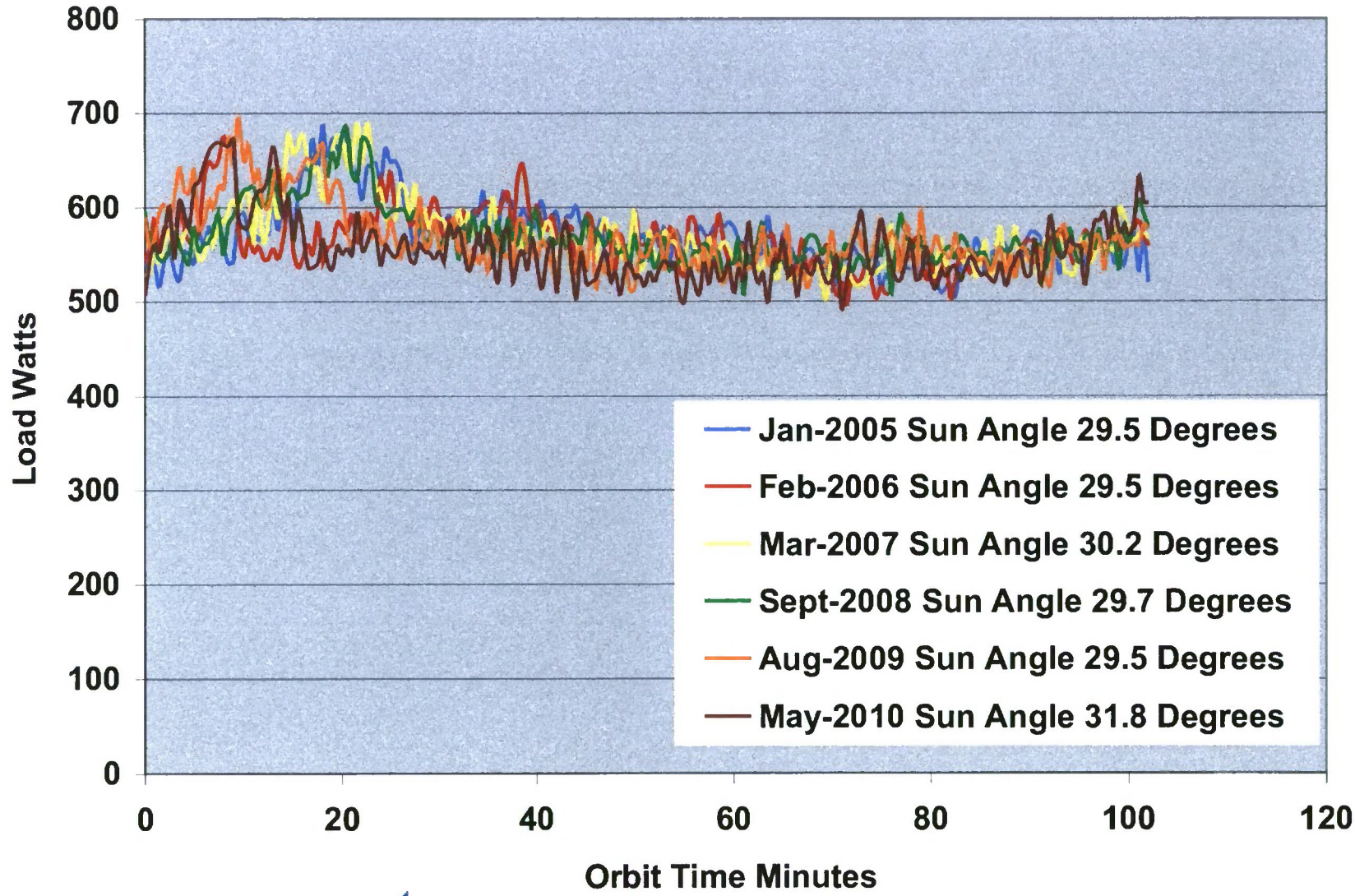
Orbit Average Load for F-16 at Sun Angle 30° and SADLAG 0°

Date	Orbit Number	Sun Angle	Orbit Average Load Watts
1-14-2004	1246	29.1	514
1-14-2004	1247	29.1	516.5

F-16 Load Data for Sun Angle 30° with SADLAG of 55°



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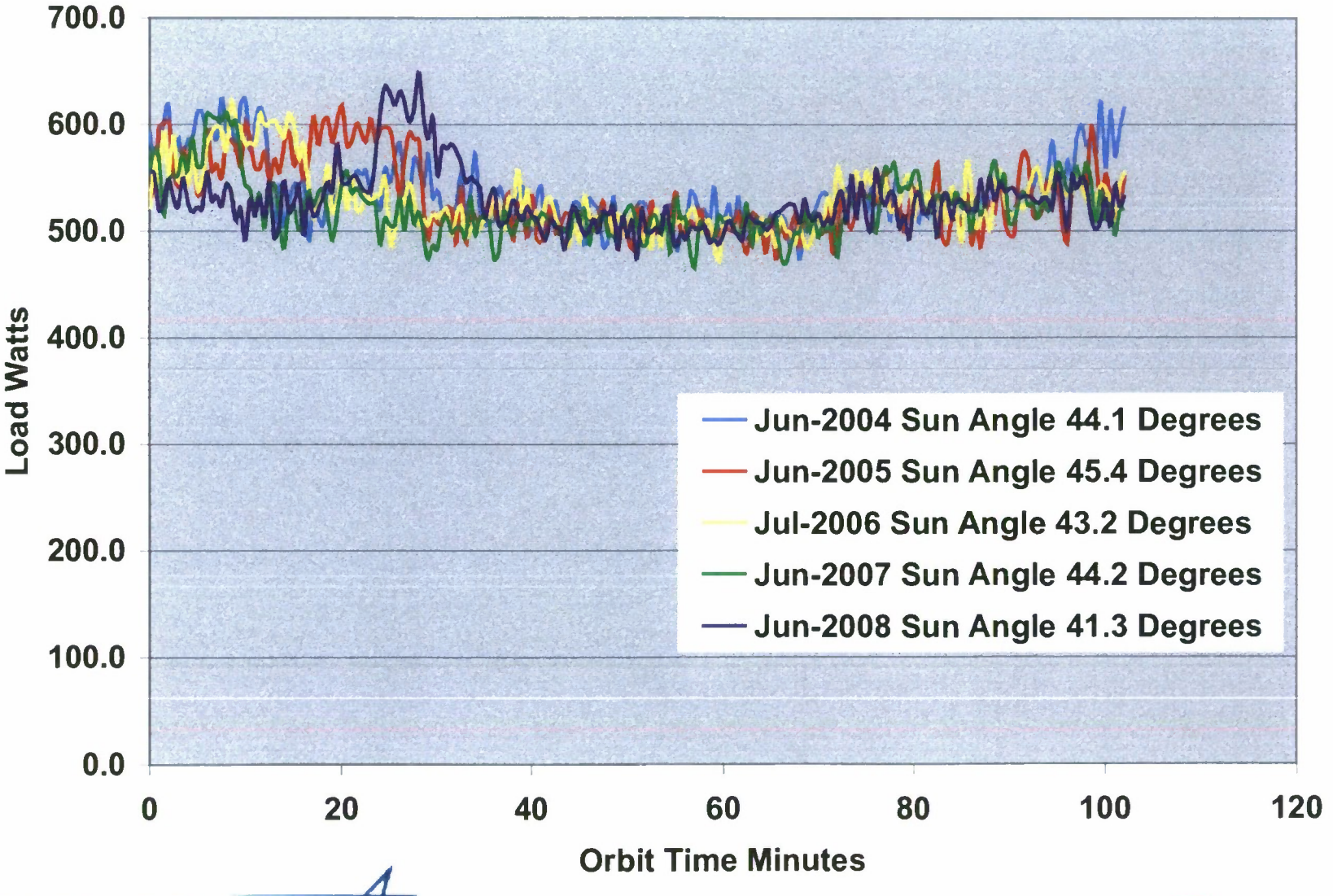
Orbit Average Load for F-16 at Sun Angle 30° and SADLAG 55°

Date	Orbit Number	Sun Angle	Orbit Average Load Watts
1-15-2005	6448	29.5	570.7
2-15-2006	12015	29.5	566.4
3-15-2007	17566	30.2	568.8
9-15-2008	25334	29.7	570.6
8-17-2009	30078	29.5	568.2
5-15-2010	33909	31.8	555.0

F-16 Load Change due to Change from SADLAG = 0° to SADLAG = 55° at Sun Angle of 30°

- Average load for SADLAG of 0° = 515 watts
- Average load for SADLAG of 55° = 566 watts
- Average additional heater load for SADLAG of 55° = 51 watts

F-16 Load Data for Sun Angle 45° with SADLAG of 55°



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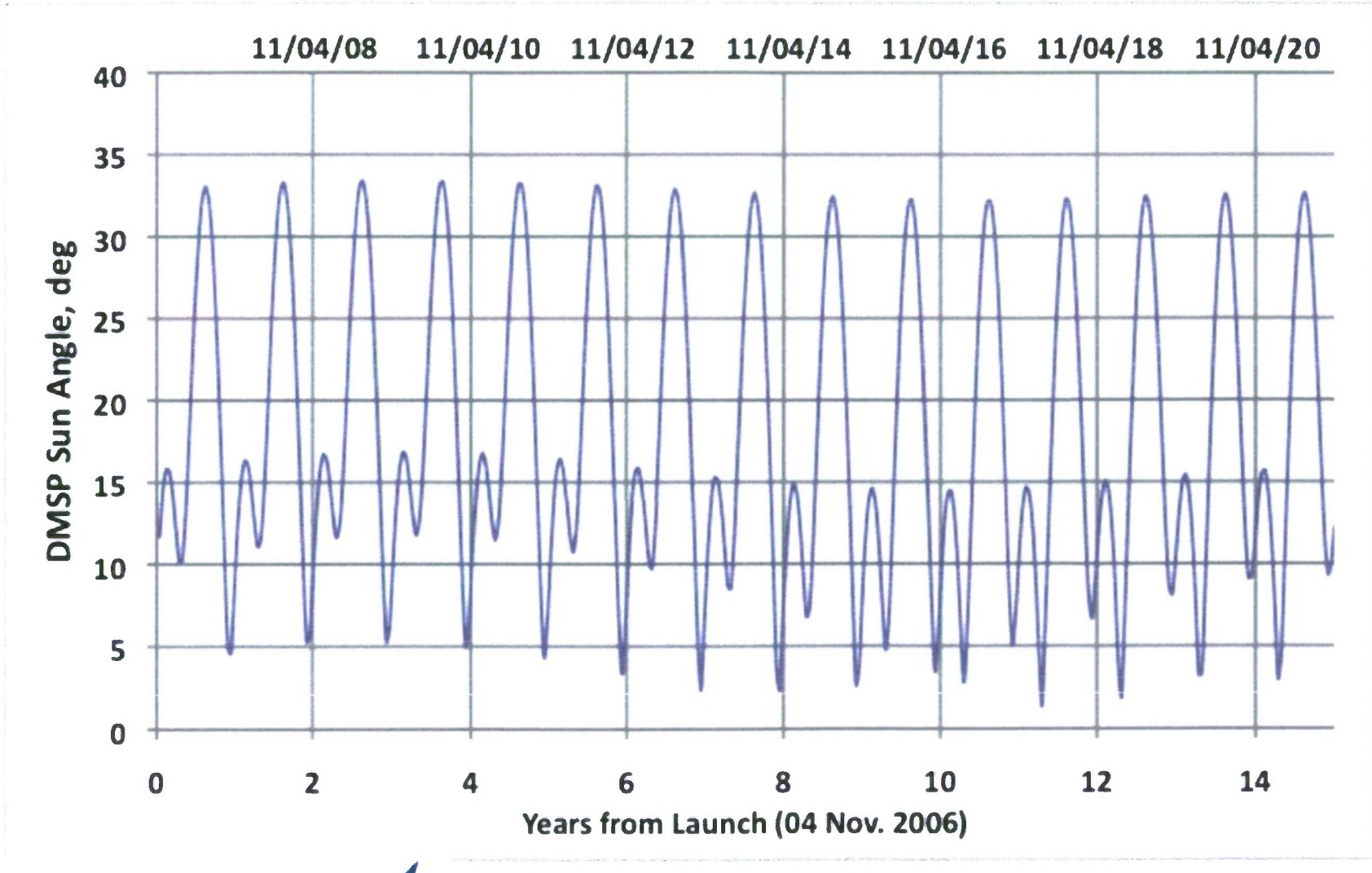
Orbit Average Load for F-16 at Sun Angle 45° and SADLAG 55°

Date	Orbit Number	Sun Angle Degrees	Orbit Average Load Watts
6-15-2004	3389	44.1	537.2
6-15-2005	8566	45.4	532.4
7-15-2006	14160	43.2	529.6
6-15-2007	18866	44.2	521.6
6-25-2008	24180	41.3	528.1

DMSP F17 Sun Angle Prediction



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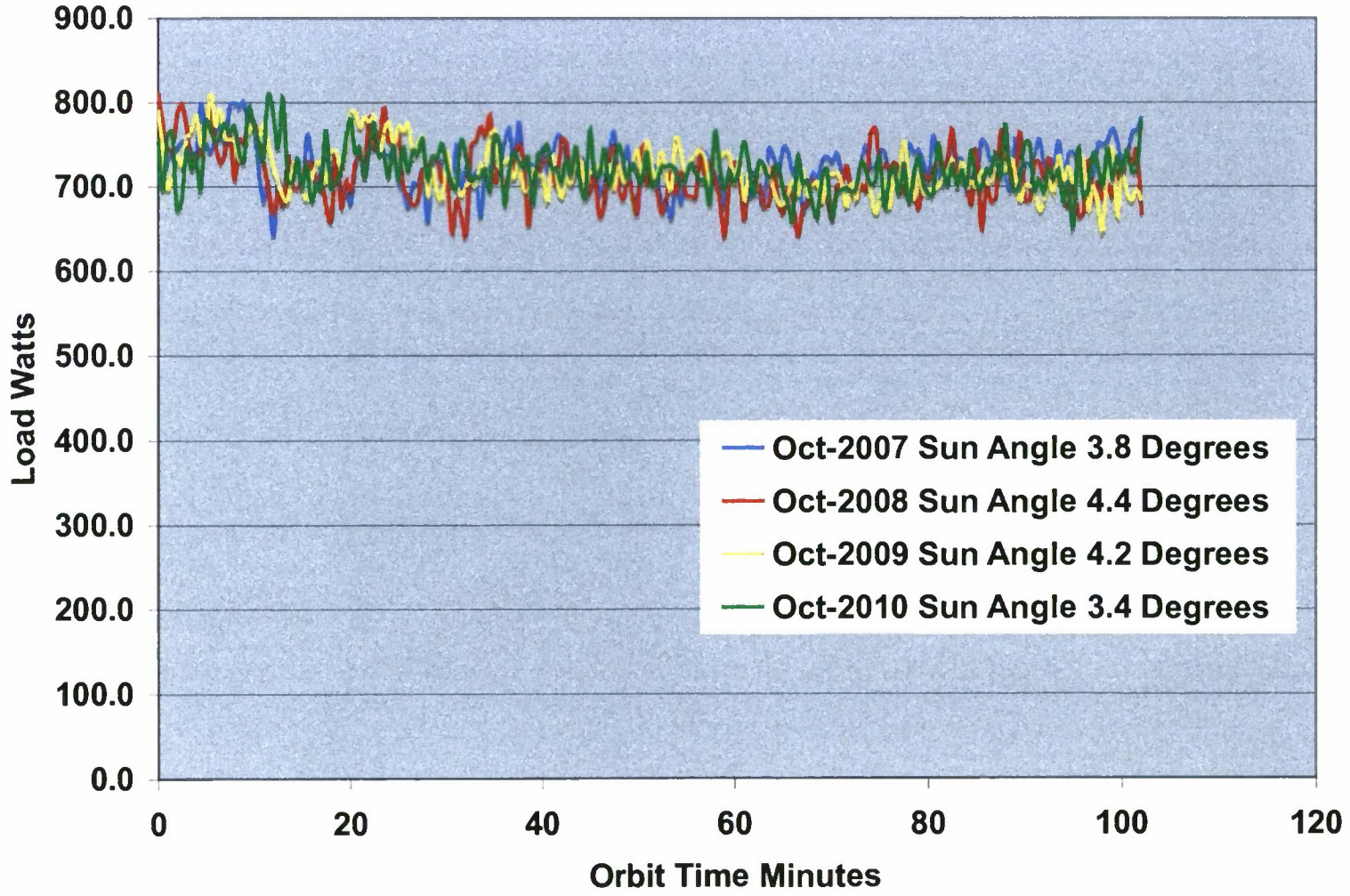
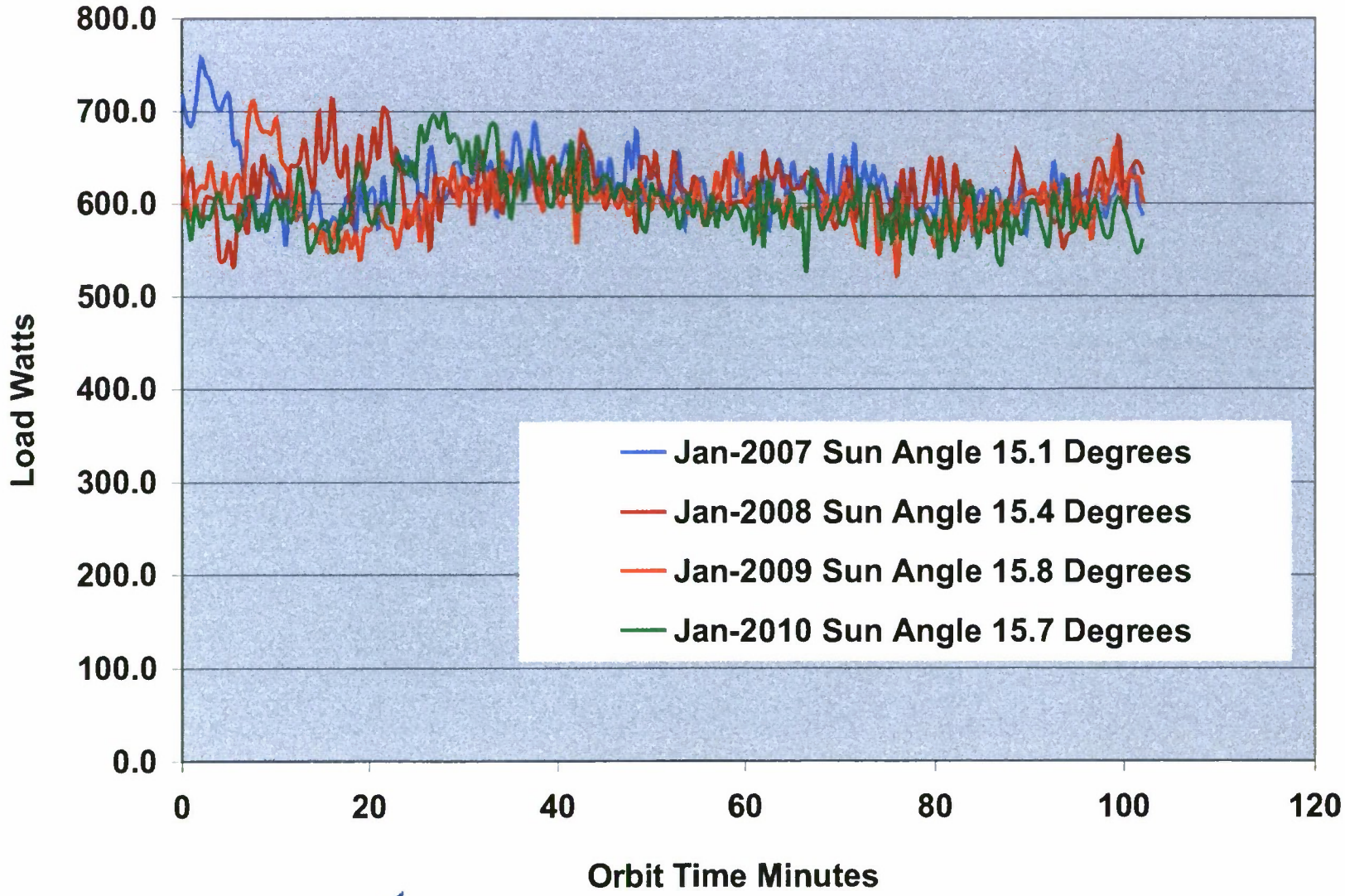
F-17 Load Data for Sun Angle 0-5° with SADLAG of 0°



Orbit Average Load for F-17 at Sun Angle 0°–5° and SADLAG 0°

Date	Orbit Number	Sun Angle Degrees	Orbit Average Load Watts
10-15-2007	4867	3.8	726.1
10-14-2008	10023	4.4	714.8
10-15-2009	15191	4.2	720.5
10-18-2010	20390	3.4	722.7

F-17 Load Data for Sun Angle 15° with SADLAG of 0°



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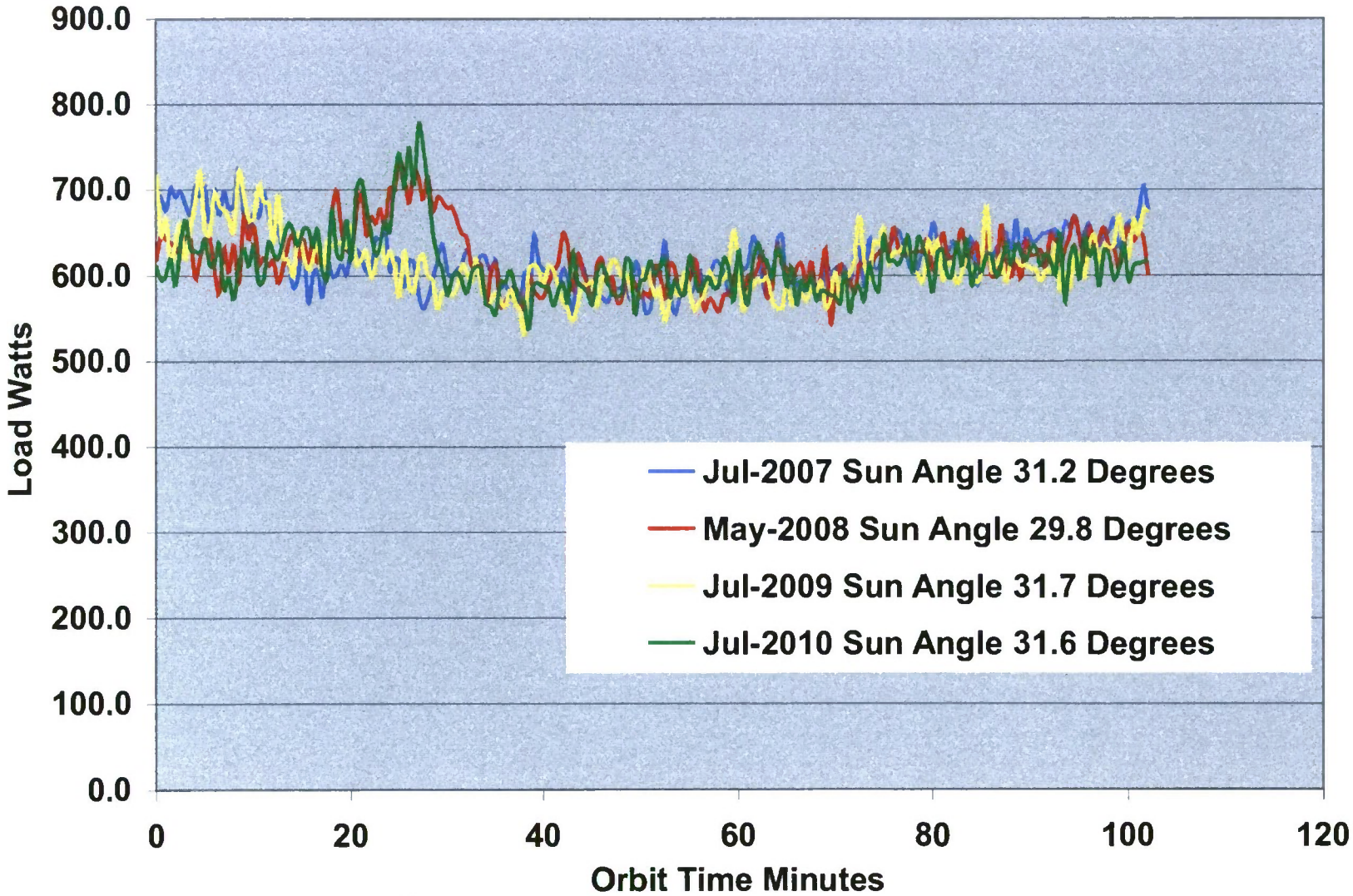
Orbit Average Load for F-17 at Sun Angle 15° and SADLAG 0°

Date	Orbit Number	Sun Angle Degrees	Orbit Average Load Watts
1-15-2007	1012	15.1	620.2
1-18-2008	6208	15.4	616.1
1-15-2009	11336	15.8	602.3
1-15-2010	16484	15.7	599.9

F-17 Load Data for Sun Angle 30° with SADLAG of 55°



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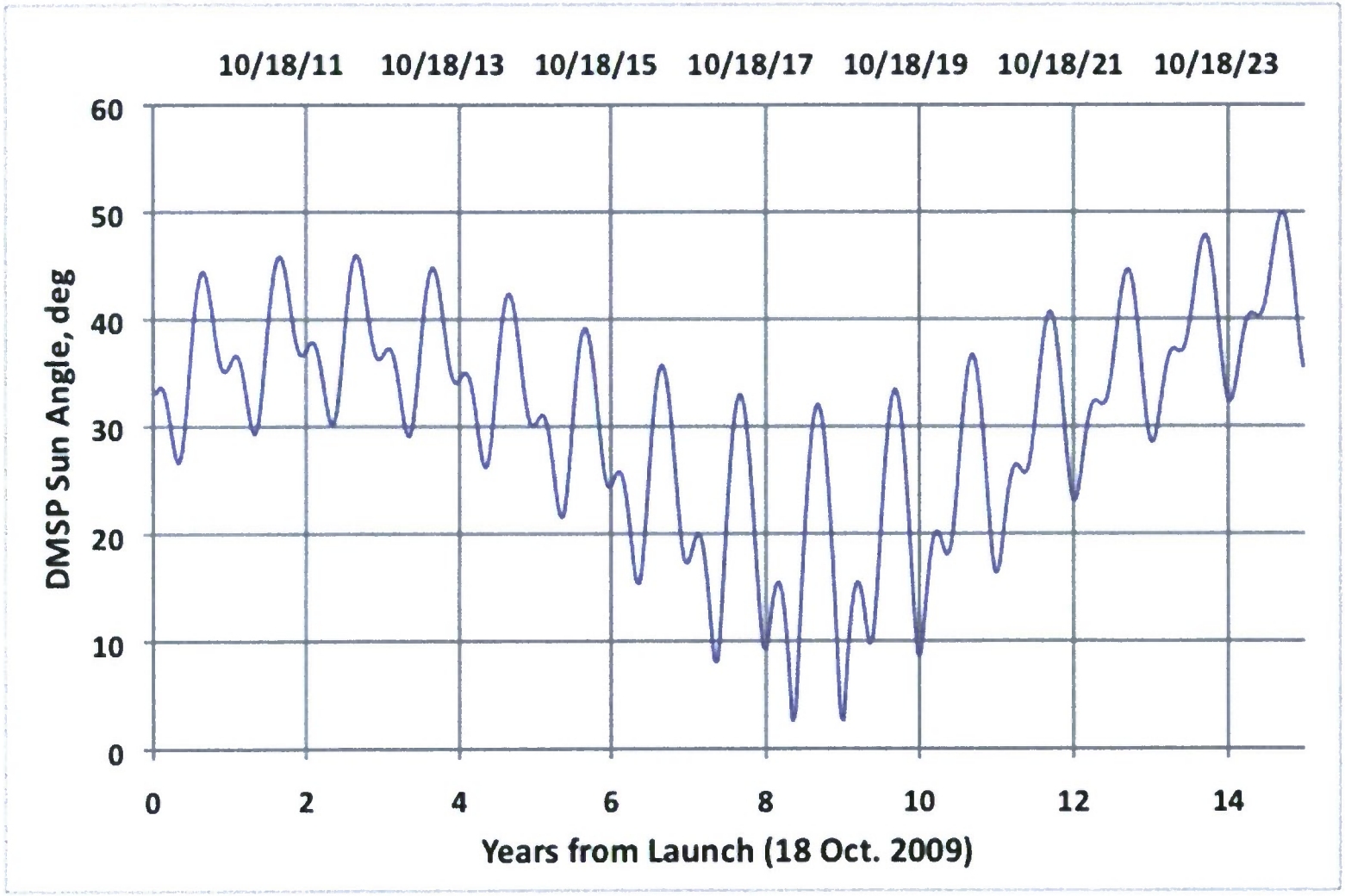
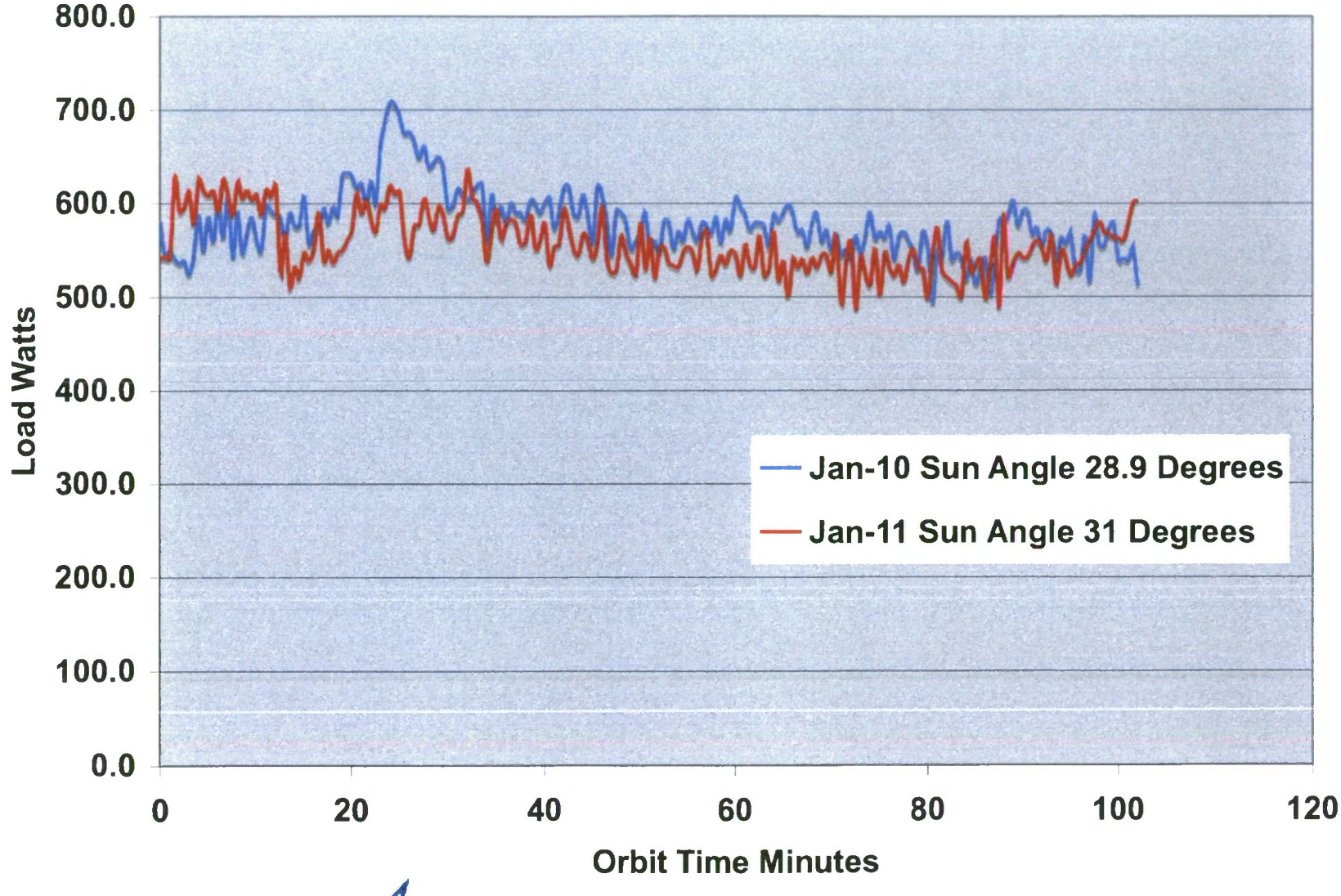
Orbit Average Load for F-17 at Sun Angle 30° and SADLAG 55°

Date	Orbit Number	Sun Angle Degrees	Orbit Average Load Watts
7-15-2007	3596	31.2	622.8
5-21-2008	7962	39.8	621.8
7-15-2009	13892	31.7	612.1
7-14-2010	19037	31.6	613.9

DMSP F18 Sun Angle Prediction



F-18 Load Data for Sun Angle 30° with SADLAG of 0°



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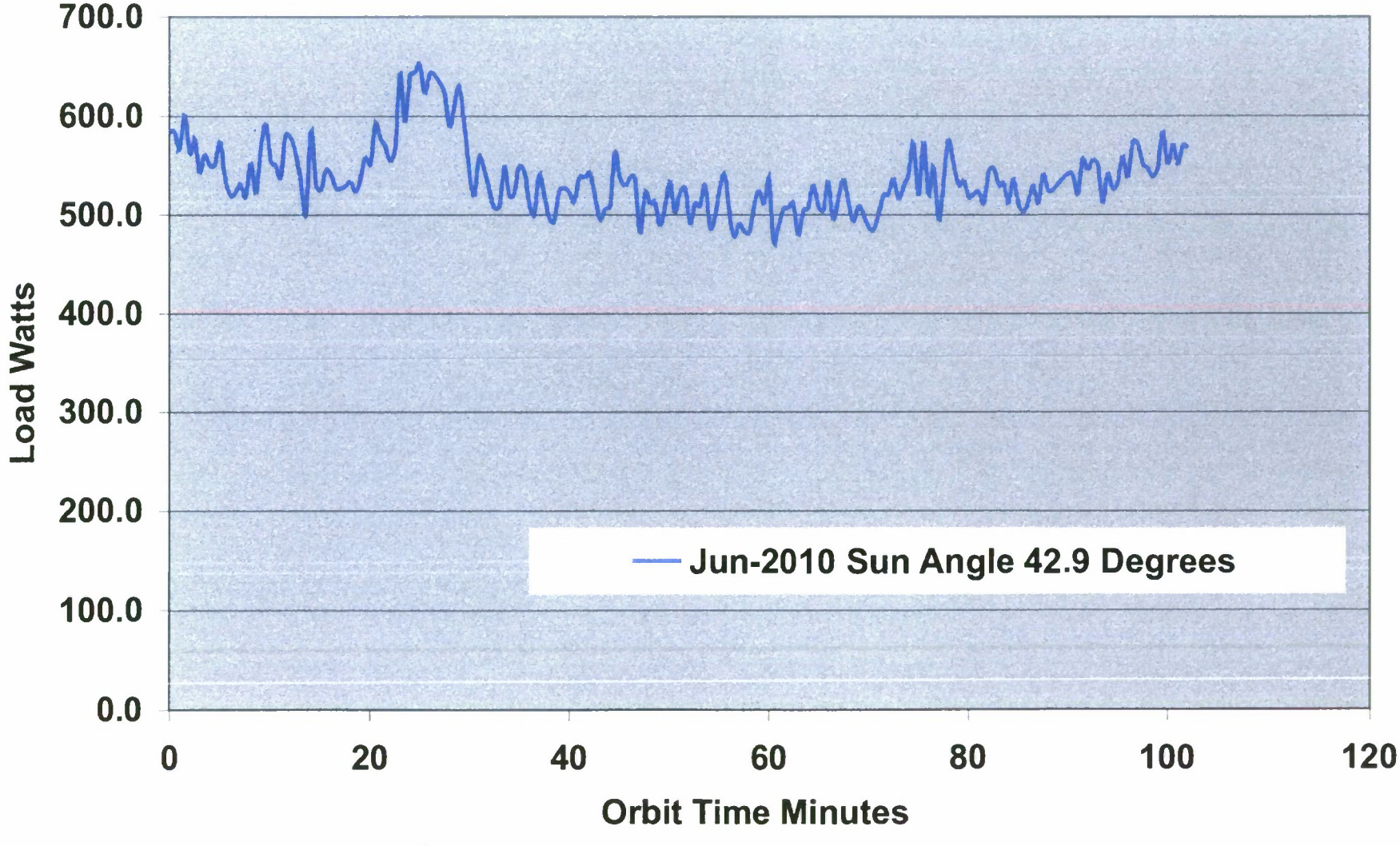
Orbit Average Load for F-18 at Sun Angle 30° and SADLAG 0°

Date	Orbit Number	Sun Angle Degrees	Orbit Average Load Watts
1-14-2010	1239	28.9	579.5
1-17-2011	6432	31.0	558.0

F-18 Load Data for Sun Angle 45° with SADLAG of 0°



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Orbit Average Load for F-18 at Sun Angle 45° and SADLAG 0°

Date	Orbit Number	Sun Angle Degrees	Orbit Average Load Watts
6-17-2010	3384	42.9	538

Comparison of F-16, F-17 and F-18 with Sun Angle of 30° to Determine Added Load for MIMU

- SADLAG 0°
  - *Average F-16 load is 515 watts*
  - *Average F-18 load is 568 watts*
  - *Added load due to MIMU and larger battery 3 radiator is 53 watts*
- SADLAG 55°
  - *Average F-16 load is 566 watts*
  - *Average F-17 load is 617 watts*
  - *Added load due to MIMU is 51 watts*

The Aerospace Corporation Energy Balance Model Validation

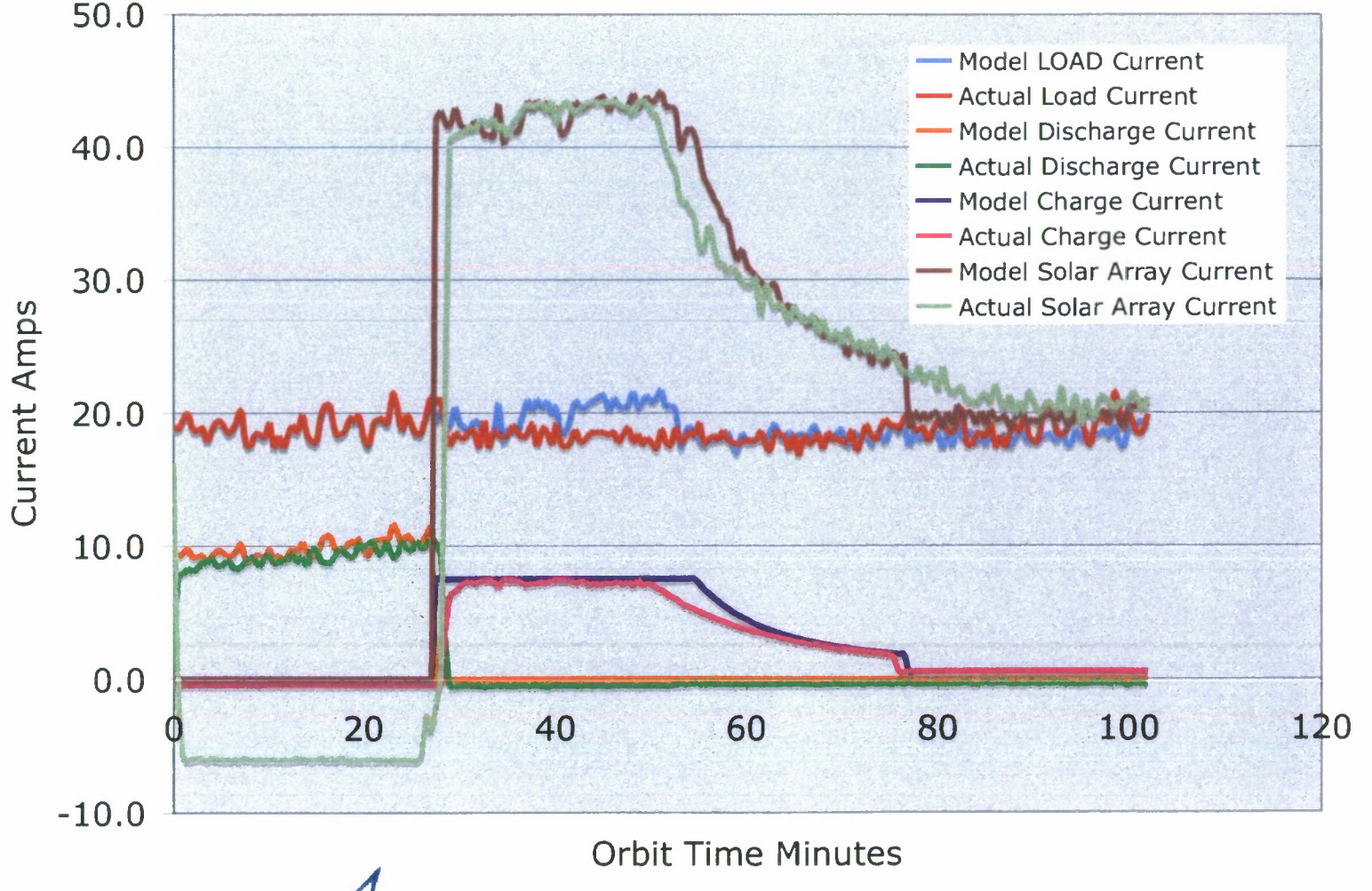
Filtering of Raw Telemetry Data for Energy Balance Model Validation

- Aerospace DMSP energy balance model uses 0.5 minute time steps
- To validate Aerospace energy balance model a load input data file was generated from actual spacecraft telemetry
  - *Telemetry data has six data points per minute*
  - *Filtered raw telemetry by averaging the three telemetry data points for each 0.5 minute model load data point*

Validation Of Aerospace Energy Balance Model

- Aerospace energy balance model includes a solar array model which includes:
  - *Sun angle*
  - *Time of year*
  - *Cant angle*
  - *Number of years on orbit*
- Aerospace energy balance model includes:
  - *Model of the battery charger V/T curves*
  - *NiCd battery charge/discharge characteristic*
- Comparison of solar array output and battery charge/discharge currents from actual spacecraft with model using actual loads as forcing function will validate model
- Actual spacecraft data was filtered for comparison

Comparison of Actual Spacecraft Data to Aerospace Energy Balance Model Rev's 8566/8567 after 2 Years on Orbit



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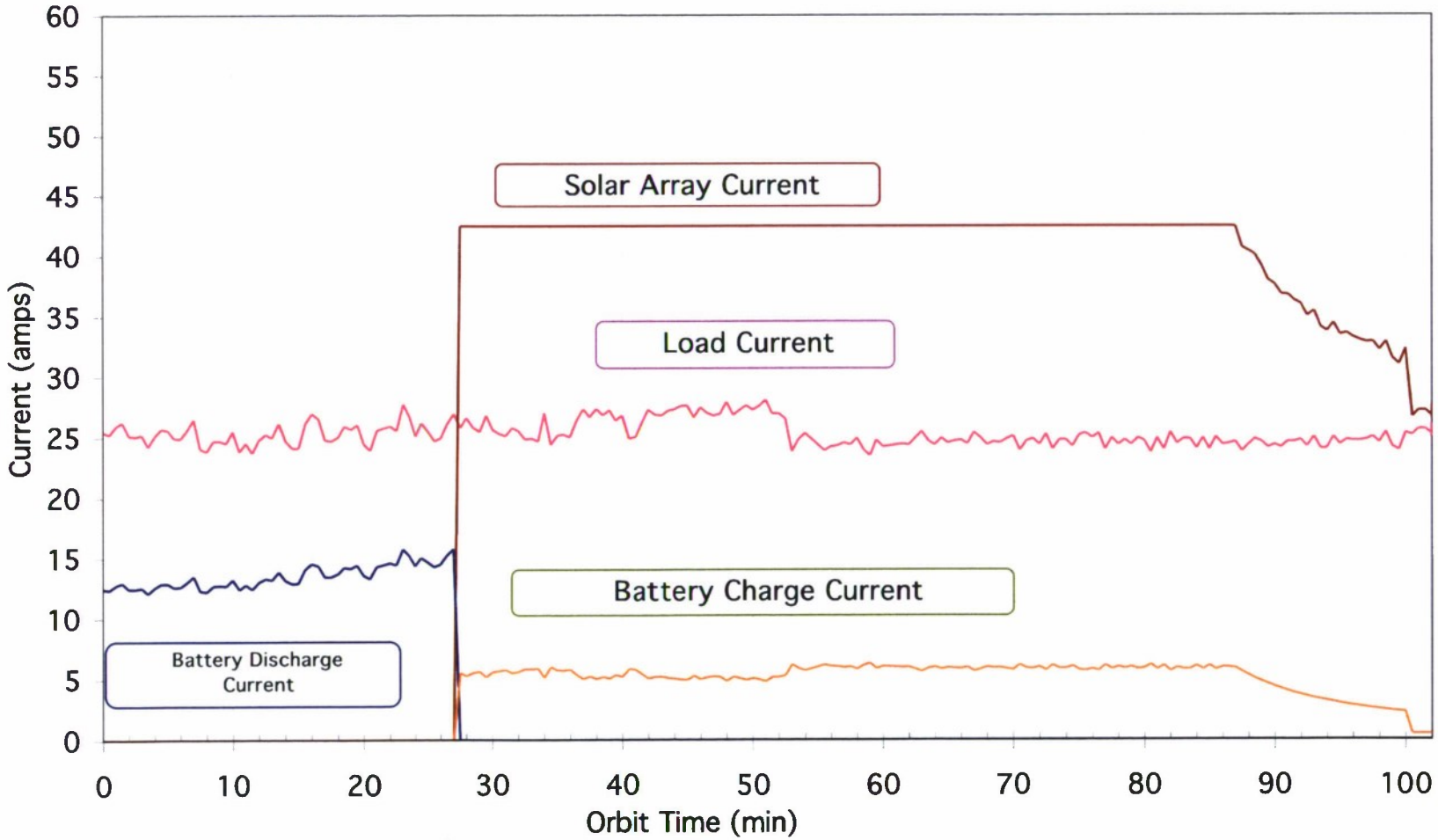
Comparison of Actual Spacecraft Data to Aerospace Energy Balance Model

- Solar array and battery discharge currents calculated by model match actual measured values
- Battery charge currents calculated by model differ slightly from actual measured values
  - *Peak charge currents match*
  - *Model predicts beginning of taper charge later than actual data*
  - *Model predicts beginning of trickle charge with a high degree of accuracy*
- Model is considered to be validated with the caveat that predicted battery charge currents for actual satellite may differ slightly

Power System Margin at Sun Angle of 45°

DMSP F-16 Energy Balance Predicts 5 Years EOL, Sun Angle 45°, SADLAG 55°, Month of June, with 180 Watts Added Load and 10 Amp Battery Charge Rate



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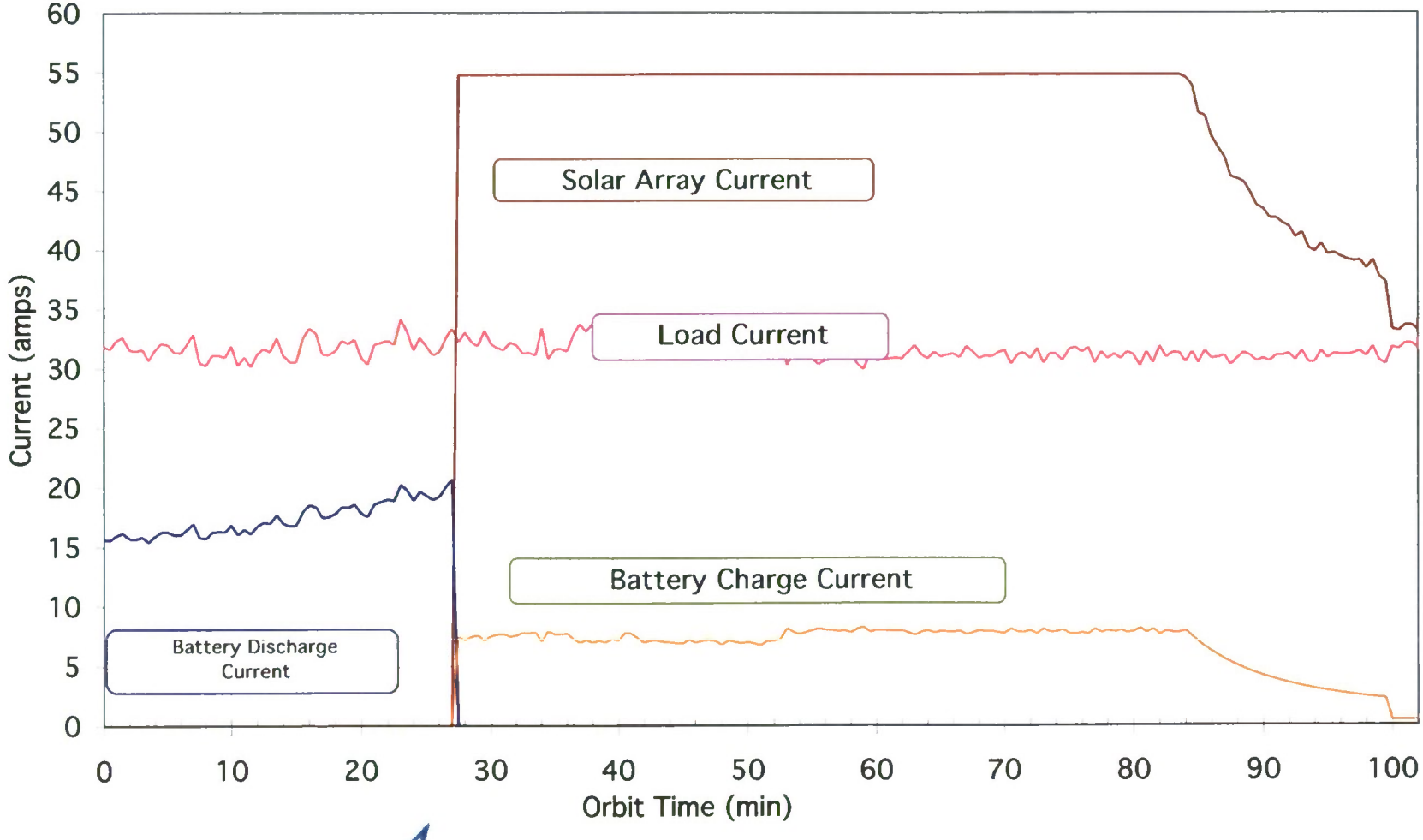
DMSP F-16 Energy Balance Predicts 5 Years EOL, Sun Angle 45°, SADLAG 0°, Month of June, with 360 Watts Added Load and 10 Amp Battery Charge Rate



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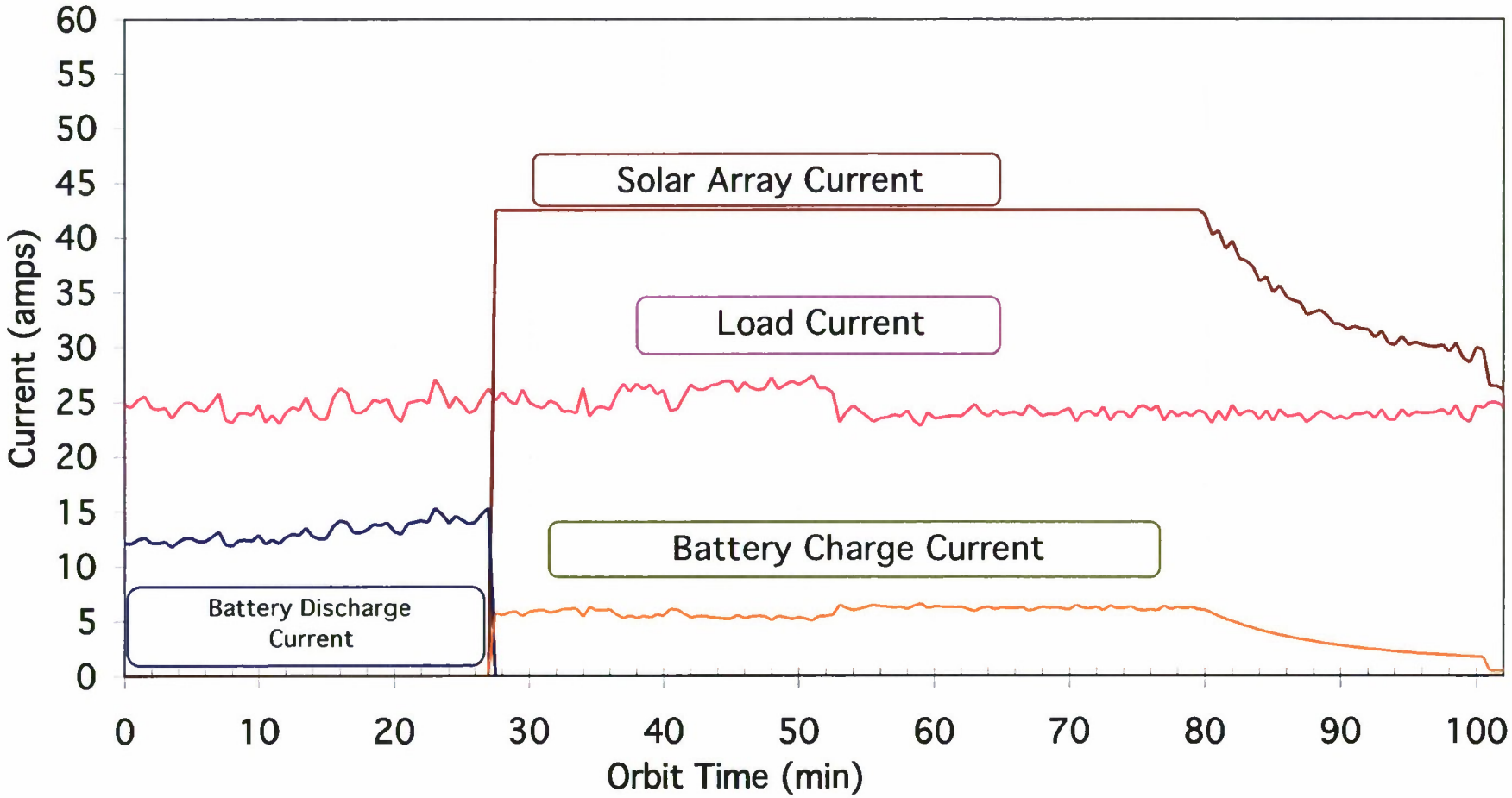
DMSP F-16 Energy Balance Predicts 5 Years EOL, Sun Angle 45°, SADLAG 55°, Month of June, with 160 Watts Added Load and 7.5 Amp Battery Charge Rate



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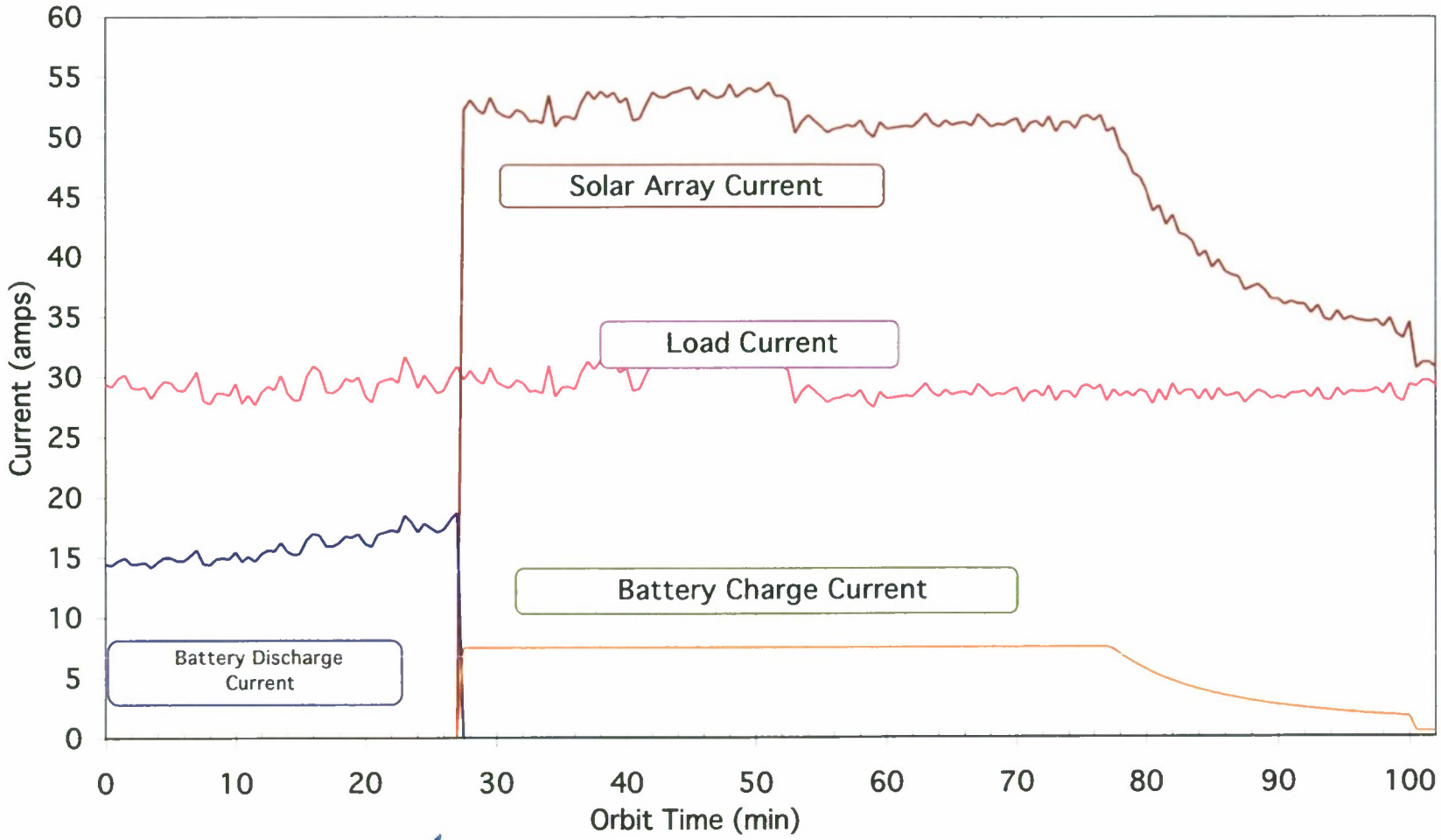
DMSP F-16 Energy Balance Predicts 5 Years EOL, Sun Angle 45°, SADLAG 0°, Month of June, with 290 Watts Added Load and 7.5 Amp Battery Charge Rate



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Power Margin for DMSP F-16 as function of Battery Charge Rate and Solar Array SADLAG at Sun Angle of 45°

SADLAG Degrees	7.5 Amp Battery Charge Rate	10 Amp Battery Charge Rate
0	290 Watts	360 Watts
55	160 Watts	180 Watts

Conclusions

- Orbit load data shows little change over many years at same sun angle
- SADLAG of the solar array has an impact on the heater loads of the spacecraft
- Spacecraft power margin is a function of spacecraft age, sun angle, SADLAG, battery charge rate and spacecraft configuration
- Orbit load data essential as input to energy balance models to determine spacecraft margins

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